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TRANSIENT AND STEADY PERFORMANCE OF AN ION ROCKET THRUST AUGMENTOR

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

GRANT No. G-570

FLUID DYNAMICS AND DIFFUSION LABORATORY
COLLEGE OF ENGINEERING
COLORADO STATE UNIVERSITY
FORT COLLINS, COLORADO

NAG 570

SUMMARY REPORT

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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Technical Management
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Electric Propulsion Office
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TRANSIENT AND STEADY PERFORMANCE OF AN ION ROCKET THRUST AUGMENTOR

SUMMARY

The grant for the year 1964 included the design, construction and operation of a vacuum facility to do research on ion propulsion units. A cesium contact ion source with an electrostatic accelerator was also designed, constructed and put in operation. A thrust augmentor system is incorporated in the accelerator system. Preliminary measurements of the ion propulsion system in operation have been made.

A theoretical study of the acceleration of ions due to counter-current electron flow and secondary electron emission at the ion emitter has been made. The assumed model and solution indicates an increase in ion beam power is possible. However, the solution failed to give increases in ion beam power, equivalent to those observed experimentally.

A literature survey of the emission of secondary electrons has been prepared. Both the theoretical and experimental data reported on secondary electron emission at metal surfaces have been reviewed. An experimental program is underway to evaluate the secondary electron emission from porous tungsten ionizers.

INTRODUCTION

The present research program is directed toward understanding and improving the present state of the art of electrostatically accelerating ions. Present ion accelerator systems are limited by space charge effects. Maximum efficiency of an ion rocket would be obtained if it could be operated ion-limited rather the space-charge-limited. In other words, at present it is not always possible to accelerate all ions produced. A possible technique for overcoming the space charge limiting condition is to introduce electrons into the accelerator system. A single set of crude data was reported, ref. 1, which did indeed suggest that electrons can greatly improve the acceleration of ions.

The first phases of the research program at CSU are reported in this paper. An experimental facility was designed, built and put into operation during the first year for the grant. A cesium contact ion rocket with provisions for the injection of electrons was also operated on a trial basis. Further work on the development of a practical rocket for the experimental study is now in progress.

A theoretical model to explain the acceleration of ions due to the counter flow of electrons is also being sought. Previous study, ref. 2, failed to indicate increases of the order experimentally observed. Thus a theoretical model based on the emission of secondary electrons from the ionizer surface was investigated during the first years' grant. The result of this study still does not give power increases as great as those observed. Further evaluation of the theoretical analysis will be necessary in order to explain the results. Apparently the use of a non-interacting steady state ion-electron flow model may be too simple for the problem.

Work is also underway to evaluate the production of secondary electrons at the ionizer. The evaluation of secondary electron emission from a porous tungsten, cesium coated ionizer is now beginning. A general literature review of secondary electron emission is included as a part of this report.

I. Vacuum Facility

The 4 foot diameter by 15 foot long, vacuum chamber built during the present grant period is shown in figures 1. The chamber is now in routine operation. Under ideal conditions the chamber can be evacuated to less than 3×10^{-7} torr in approximately 1 1/2 hours starting at atmospheric pressure. With an ion engine in operation and probes actuated through the vacuum seals, the operating pressure is usually in the 10^{-6} torr range. The operations manual for the chamber is included as appendix A of this report.

II. Cesium Contact Ion Propulsion System

As outlined in the interim report, ref. 3, a porous tungsten-cesium contact ion propulsion system was designed for the experimental study. Figure 2 is a photograph of the completed system. The complete system is mounted with ceramic insulators on a brass plate. The brass plate is in turn mounted on two rails with small ceramic insulators. The brass mounting plate is, thus, insulated both from the voltages applied to the system and also from ground potential. In this way the breakdown of accelerator voltages to ground potential requires the failure of two insulators. The porous tungsten ionizers were shown in ref. 3. Evaluation of the properties of the ionizer is still in progress. First attempts to measure the volume flow rate through the ionizers gave unrealistic values for the porosity. These measurements are being repeated with improved measuring instruments.

Limited data on the operation of the ion system has been obtained in the preliminary tests. Figure 3 is a typical set of data plotted as cesium ion current density versus cesium resevoir temperature curve. The ionizer temperature was approximately 1660^{0}F for the data shown.

As may be seen in figure 3 a condition of space-charge-limited flow was obtained for the + 1K, -2K volt condition. Figure 4 compares the ion current density obtained for the low temperature operating conditions with data reported by Kuskevics and Thompson, ref. 4, for simular ionizers. The extrapolated agreement indicates that the porous tungsten ionizers are operating as expected.

The major difficulty encountered in operating the ion system has been the development of the ionizer heater. First attempts used tantalum heater wires imbedded in a ceramic material, Rokite A which is a sprayed alumina coating. Difficulty was encountered in making connections to the tantalum wire. Secondly, the ceramic did not adhere to the ionizer block after several thermal cycles. The tantalum wire became brittle after it was heated and could not be further worked. The tantalum heater wire was replaced in later versions by tungsten - 26 per cent rhenium wire. The 73 W-26 Re wire can be silver soldered to connections and remains ductile after repeated thermal cycles. The ionizer heaters are now swaged in a 0.06 inch diameter metal sheath. Small ceramic (MgO) insulators are placed in the metal sheath and a 0.013 inch diameter 73 W-26 Re wire is threaded down the middle of the sheathed insulators. Both tantalum and stainless steel have been used as sheath material. Tantalum sheathes became very brittle. The stainless steel melts at temperatures slightly greater than 2000^{0}F. Tungsten - Rhenium sheath material will be employed for future heaters, however, this material costs approximately $10 per inch which means that approximately $120 per heater will be invested.

The insulator material, MgO, for the heater will hold a potential difference of only 30 volts at 2000^{0}F. Thus, it is necessary to make the heaters of low resistance (1 ohm or less) to prevent arcing from the heater wire to the ionizer block which leads to failure. The heaters have been operated at 10 amps without difficulty, as long as the voltage does not exceed approximately 30 volts.

The most important point in improving the ionizer heater was the radiation shielding. Without shielding, two hundred watts were required to reach temperatures of only 1250^{0}F at the emitter. By adding a tantalum radiation shield around the heater and ionizer block, the power required to reach 1250^{0}F was reduced by a factor of 3. The radiation shield was made of 0.005 inch thick tantalum sheet. The front of the sheet formed the focusing electrode of the emitter. A second improvement in radiation shielding was the addition of a ceramic powder to the space between the heater and the radiation shield. Figure 5 shows the actual measured improvement obtained by the radiation shielding.

III. Thrust Augmentor

The thrust augmentor tested in the initial experimental studies is shown in the photograph of figure 6. It is a 0.01 inch diameter thoriated-tungsten wire which was used to produce electrons in the accelerator region. As the study progresses the thoriated-tungsten wire will be replaced with a pure tungsten wire, so a better controlled supply of electrons will be available.

The initial run of the electron emission thrust augmentor was limited by malfunction of the cesium resevoir heater. The resevoir could be heated to only 400^{0}F, thus for most of the practical measurements the system was ion limited rather than space charge limited. Figure 7 shows some of the metered data taken during the initial run. Figure 7a is a block diagram of the electrical hook-up of the system. In figure 7a the current density is plotted as a function of cesium resevoir temperature.

Figure 7c shows the effect of varing the electron emission wire voltage without emitting electrons. Figure 7d shows the effect of varing the electron emission wire voltage while maintaining a constant emission between 8.6 and 9.0 milliamps of electrons. The limited resevoir temperature makes it impossible to draw definite conclusion from this preliminary data.

A theoretical analysis of a simple model of the thrust augmentor was made for the research grant. This analysis is presented as Appendix B of this report. The results of this analysis suggest that an adequate model to explain the physical observations is still lacking. Further development of the model will await more experimental measurements.

IV. Instrumentation

A group of three instruments have been developed to analize the ion beam; a) Hot Wire Calorimeter, b) Ion Energy Analizer, and c) Floating Emission Probe. Because of the limited operation of the ion system to date, no actual ion beam measurements have been recorded with the instruments.

A. Hot Wire Calorimeter. - Construction of the hot wire calorimeter was outlined in ref. 3. Figure 8 shows the actual probe mounted in the vacuum chamber. The sensing element is a platinum - iridium wire, 0.0004 inches in diameter and approximately 0.10 inches long. The sensing element is roughly half the length of the wires used in the original development of the calorimeter, ref. 5. The wire was shortened to reduce the radiation error encountered with the longer wires. The short wire and cooling directly at the support tips greatly reduce the background errors encountered in the original probe designs of ref. 5. The sensitivity of the wire, as determined from a calibration curve of R versus I^2 for the wire in the vacuum, as shown in figure 9, is roughly half that of the wire used in ref. 5. It remains to determine if this lesser sensitivity will be adequate for the present ion system.

The water cooled hot wire calorimeter is remotely actuated by the actuator shown on top of the vacuum chamber in figure 8. An uncooled hot wire calorimeter probe is also used in the measurements. The uncooled calorimeter is mounted to a rotating arm contained in the same mounting flange with the ion system. This uncooled calorimeter can be used to survey the ion beam at distances from roughly 1 inch from the ionizer to distances up to 15 inches along the beam. This particular acutator system will be employed with the velocity analizer and the floating emission probe.

B. Ion Energy Analizer. - A energy analizer, simular to that reported by Sellen, ref. 6, has been built for analysis of the present ion beam. A photograph of the analizer is shown in figure 10. The electronic control of the two curved plates is still being developed. An attempt is being made to utilize the high voltage power supplies used to accelerate the ions to also supply the voltage to the analizer plates.

C. Floating Emission Probe. - A floating emission probe built according to the specification of ref. 7 has also been constructed. Figure 11 is a photograph of this probe. The case of the probe was made of brass instead of stainless steel. Since the probe will be operated very close to the ion system it is expected that sputtered atom of the case material may get back to the ionizer. Thus, a metal such as brass or copper is preferred to stainless steel, since stainless steel materials would not necessarly melt when it deposited on the ionizer.

V. Secondary Electron Emission Study

A. Literature Survey. - A literature survey of both experimental and theoretical studies of secondary electron emission is given as Appendix C of this report.

B. Experimental Study. - A electron collector has been built to study the secondary emission from the porous tungsten ionizers. Figure 12 is a photograph of the collector. This collector is designed to evaluate the angular distribution of the secondary electrons. Provisions are also made to study the secondaries due to primary electrons striking at angles of incidence to the ionizer. The bell jar assembly where the secondary electron experiments are to be made is an integral part of the vacuum chamber.

CONCLUSIONS

The general research facility and instrumentation for the study of an ion rocket thrust augmentor was completed during the first year of the grant. The ion rocket system has been operated and preliminary data recorded. The preliminary operation of the ion system has led to normally expected difficulties, which are being solved at the present time.

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1. Sandborn, V. A. and Baldwin, L. V.; Hot Wire Calorimeter Study of Ion Production and Acceleration. AIAA Journal Vol. 2, No. 4, 1964.

2. Muller-Lubeck, K.; Uber Die Ambipolare Raumladungsstromung Bei Ebenen Elektroden. Lectschrift Fur Angewandte Physik, III. Band Heft II. -1951. See also Langmurs, I.; The interaction of electrons and positive ion space charges in cathode sheaths. Physic, Rev. 33, 954 (1919).

3. Transient and Steady Performance of an Ion Rocket Thrust Augmentor. Interim Report, June, 1964 to NASA from Fluid Dynamics and Diffusion Laboratory, College of Engineering, Colorado State University, Fort Collins, Colorado.

4. Kuskevics, G. and Thompson, B. L.; Comparison of Commercial, Spherical Powder, and Wire Bundle Tungsten Ionizers. AIAA Journal Vol. 2, No. 2, 1964.

5. Baldwin, L. V. and Sandborn, V. A.; Hot-Wire Calorimetry: Theory and Application to Ion Rocket Research. NASA Technical Report R-98, 1961.

6. Sellen, J. M. and Shelton, H.; Transient and Steady State Behavior in Cesium Ion Beams. Electrostatic Propulsion, Vol. 5 Progress in Astronautics and Rocketry, Academic Press, New York, 1961.

7. Design, Development, and Fabrication of a Floating Embsive Probe for Ion Beam Diagnostics. Space Technology Laboratories, Inc. Report 9240-0186, 1963.

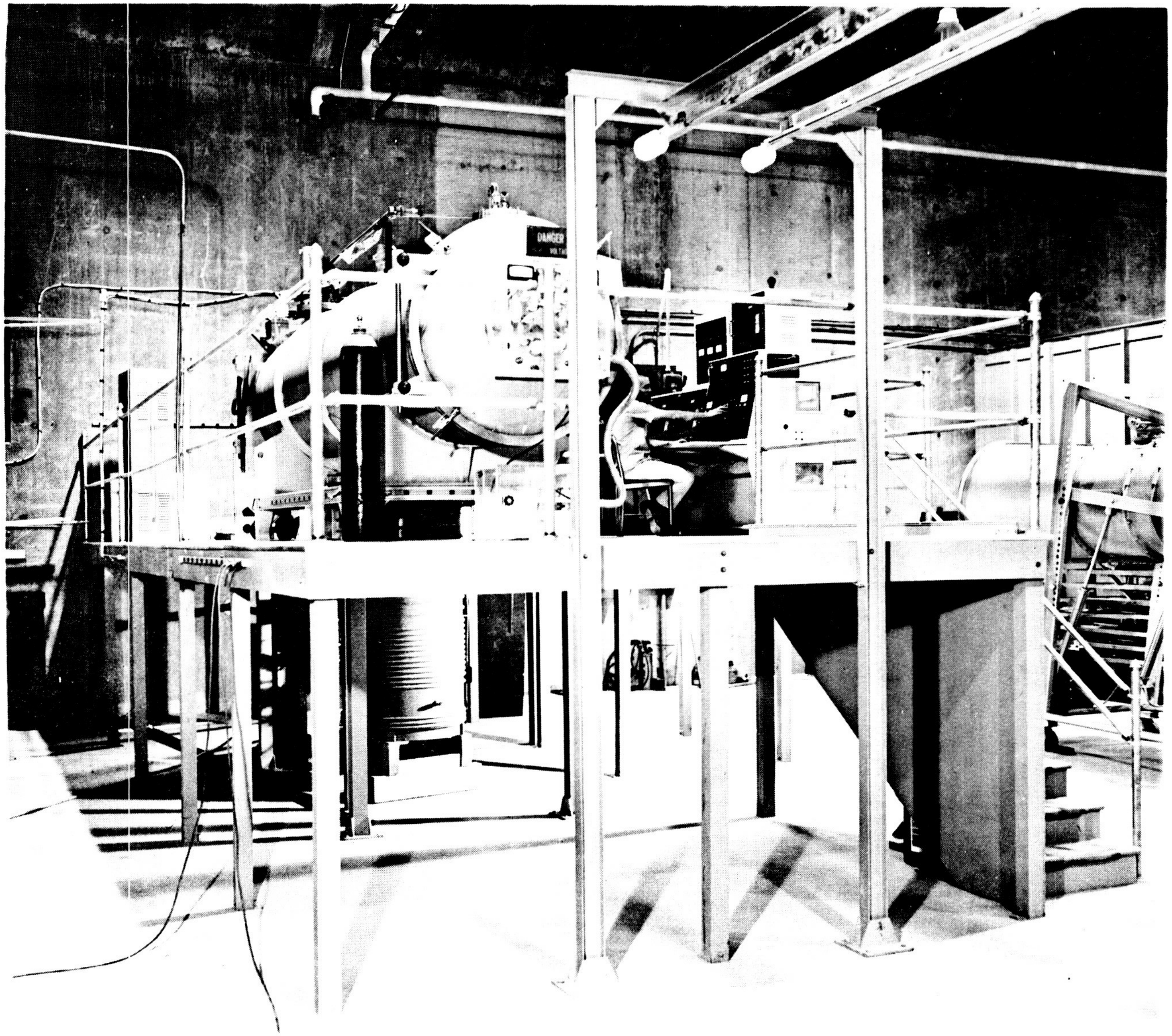


Figure 1. - CSU-NASA Ion Research Vacuum Facility

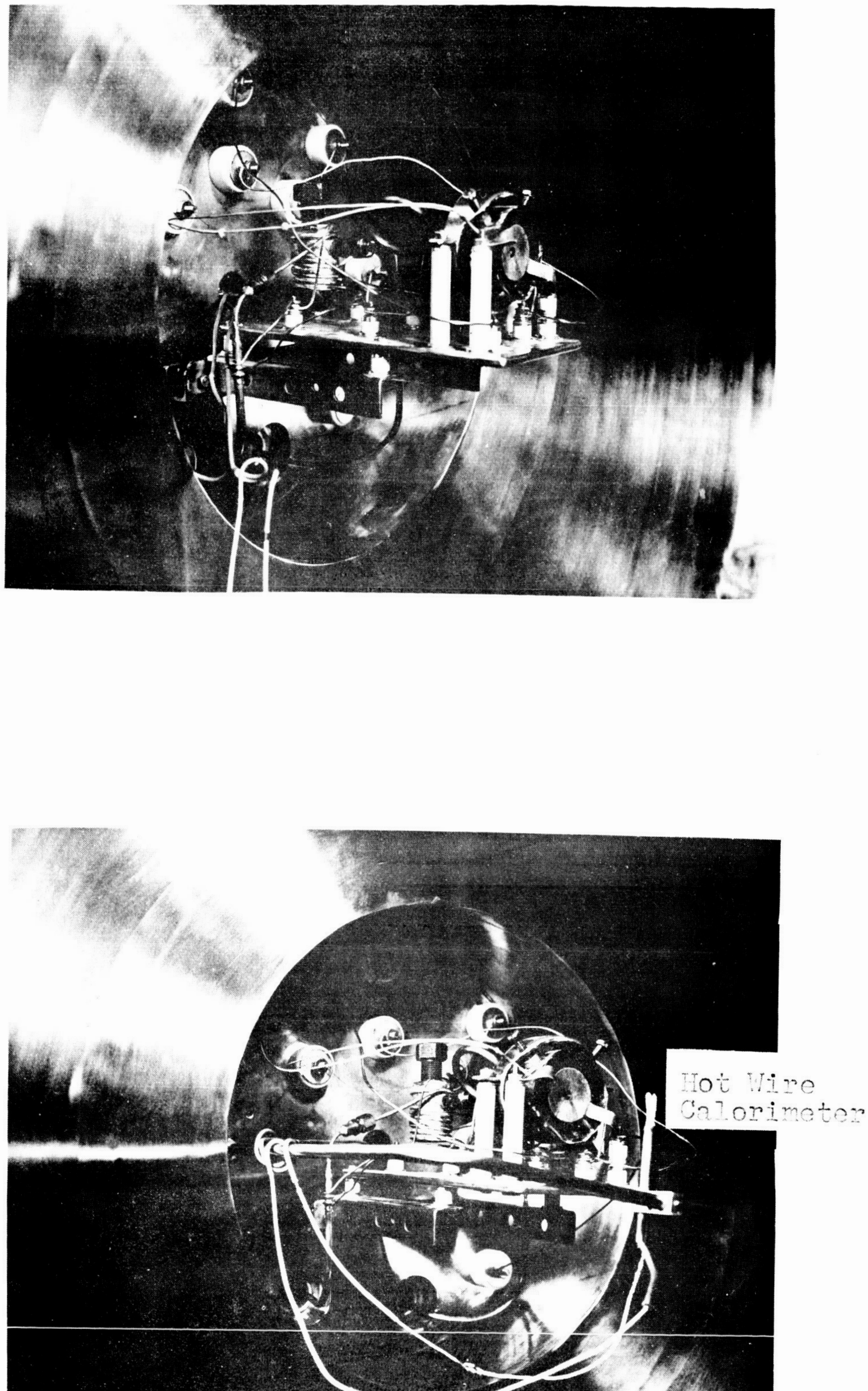


Figure 2. - Cesium Contact Ion Propulsion System

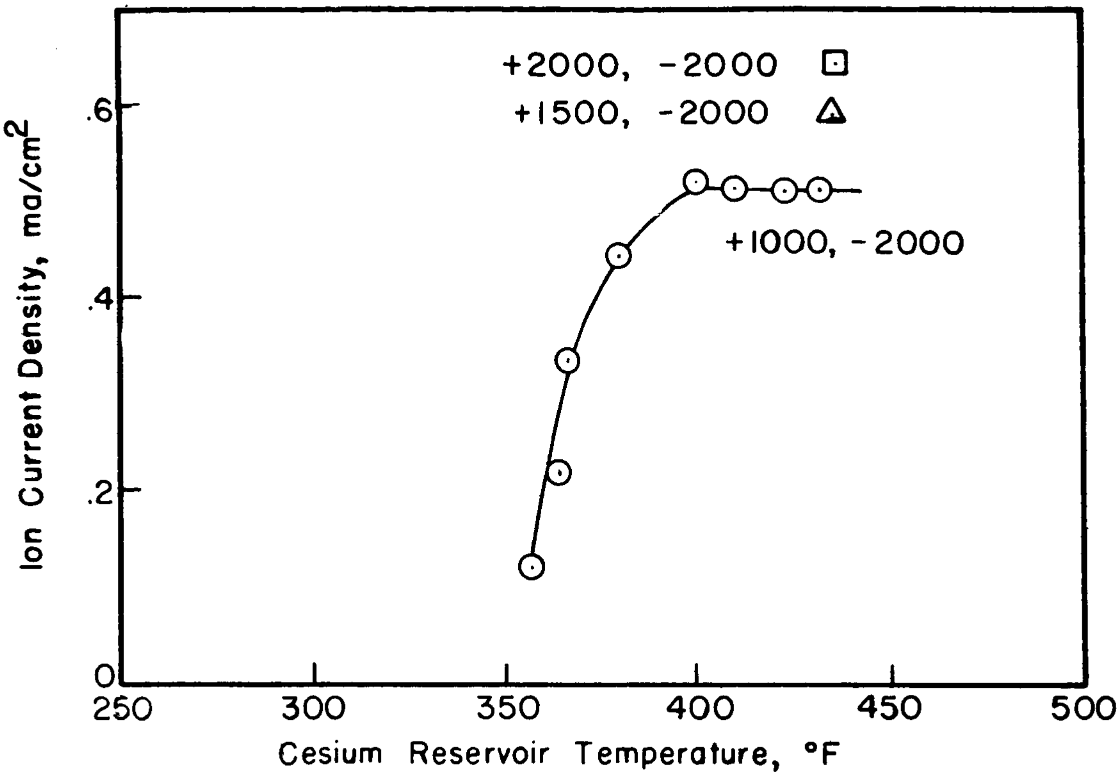


FIG. 3.- ION CURRENT DENSITY AS A FUNCTION OF CESIUM RESEVOIR TEMPERATURE. (IONIZER TEMPERATURE 1660 °F)

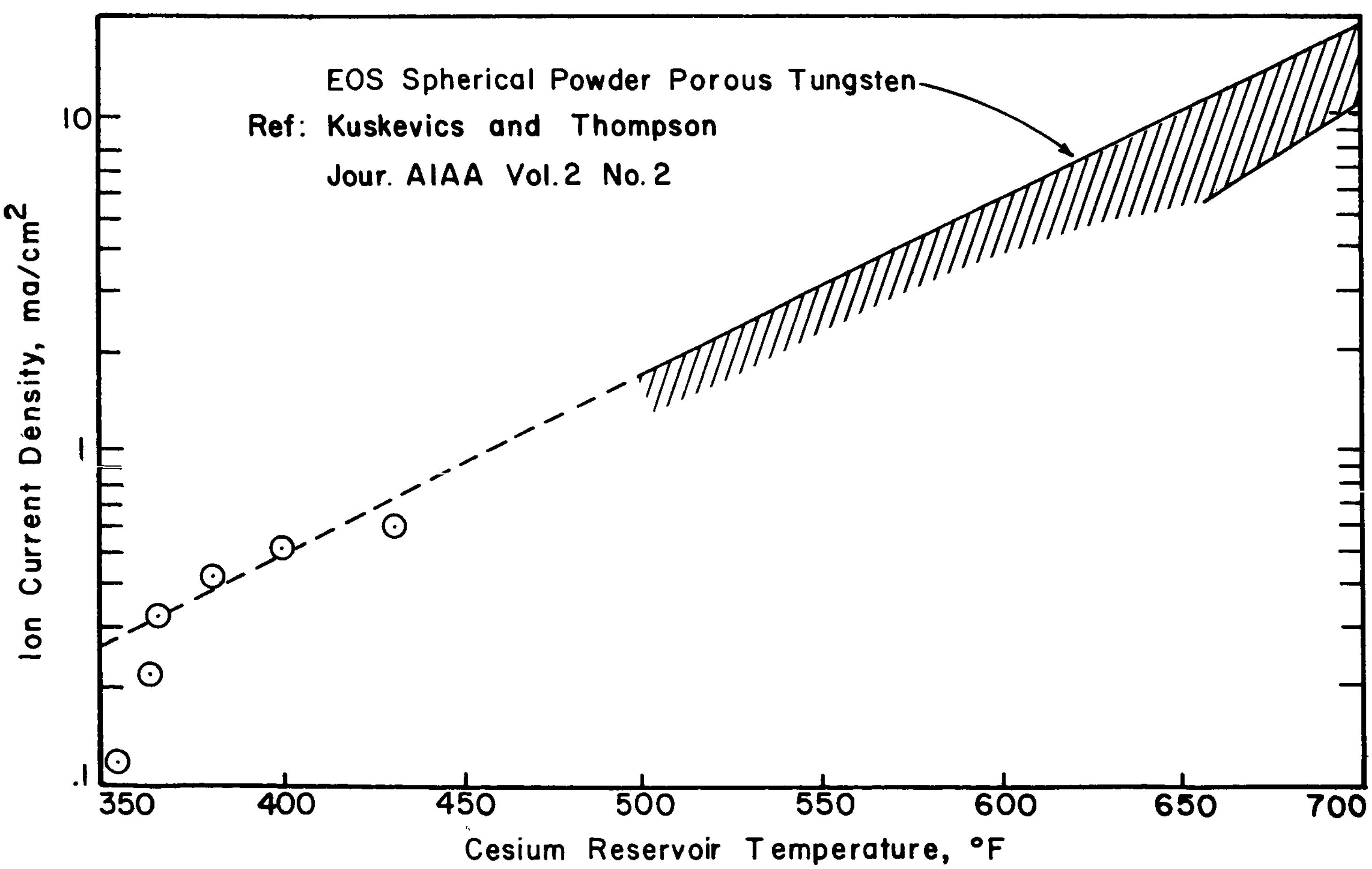


FIG. 4.- COMPARISON OF MEASURED ION CURRENT DENSITY WITH PREVIOUS REPORTED DATA.

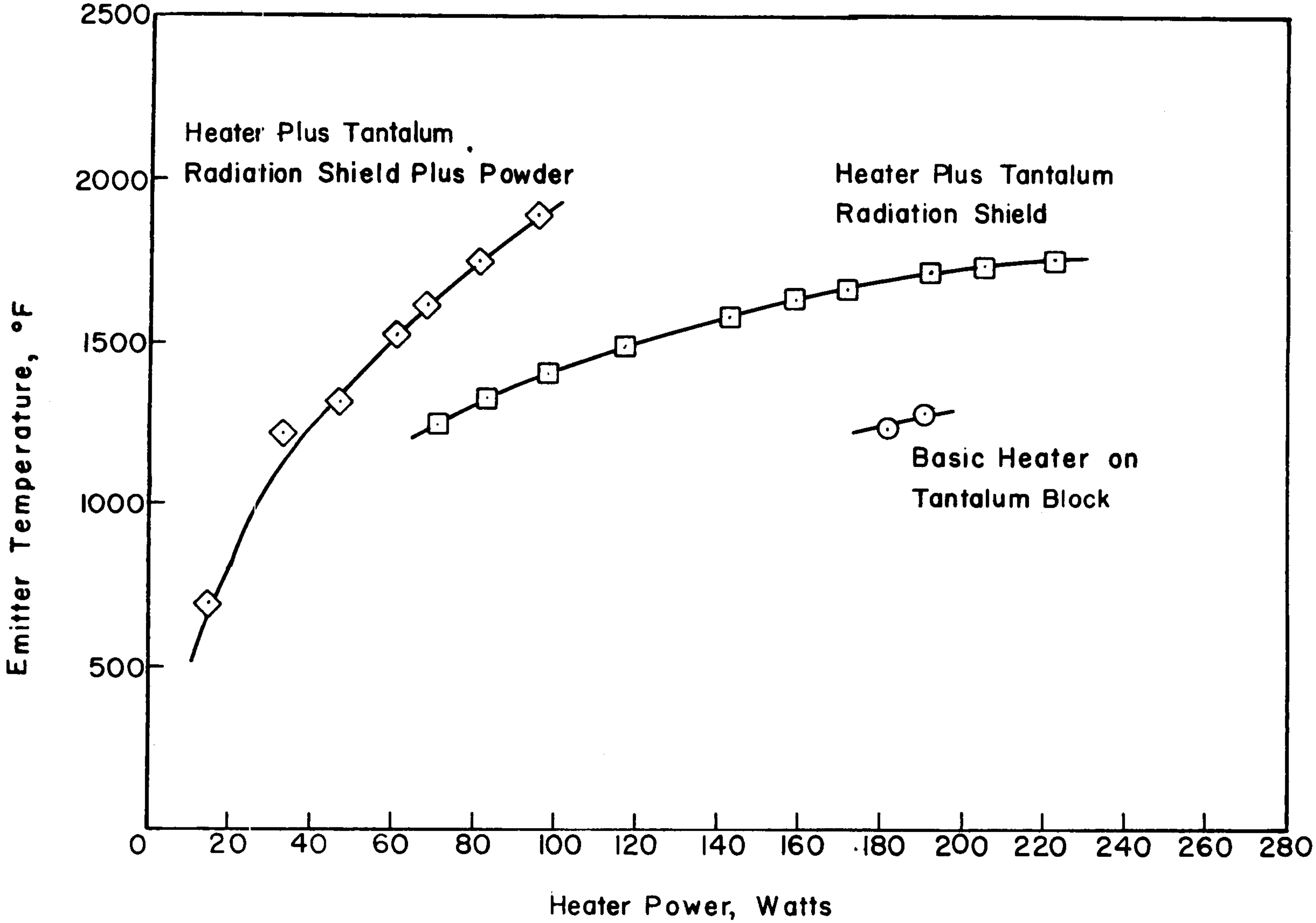


FIG. 5.- EFFECT OF RADIATION SHIELDING AND POWDER ON POWER REQUIRED TO HEAT THE IONIZER.

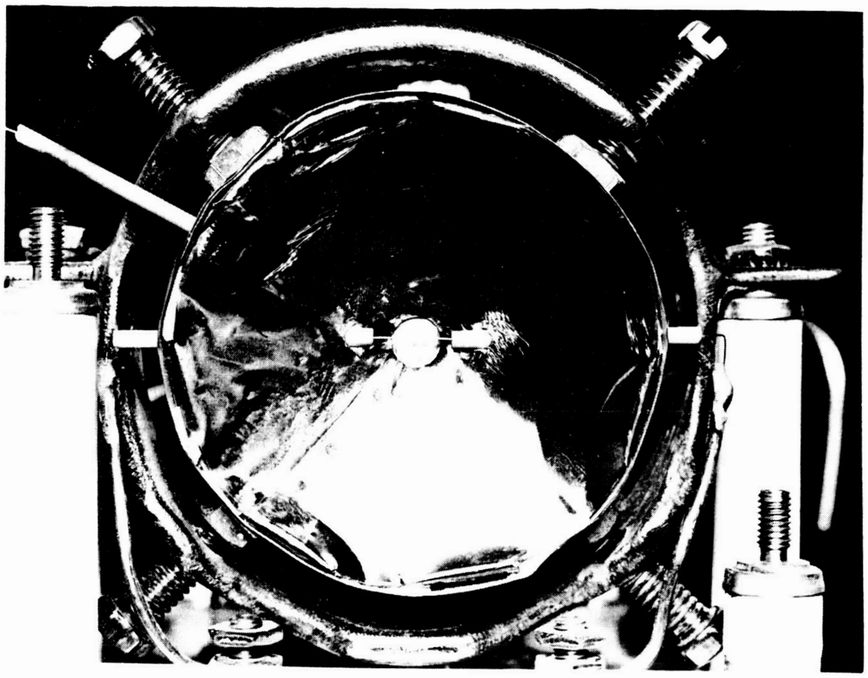
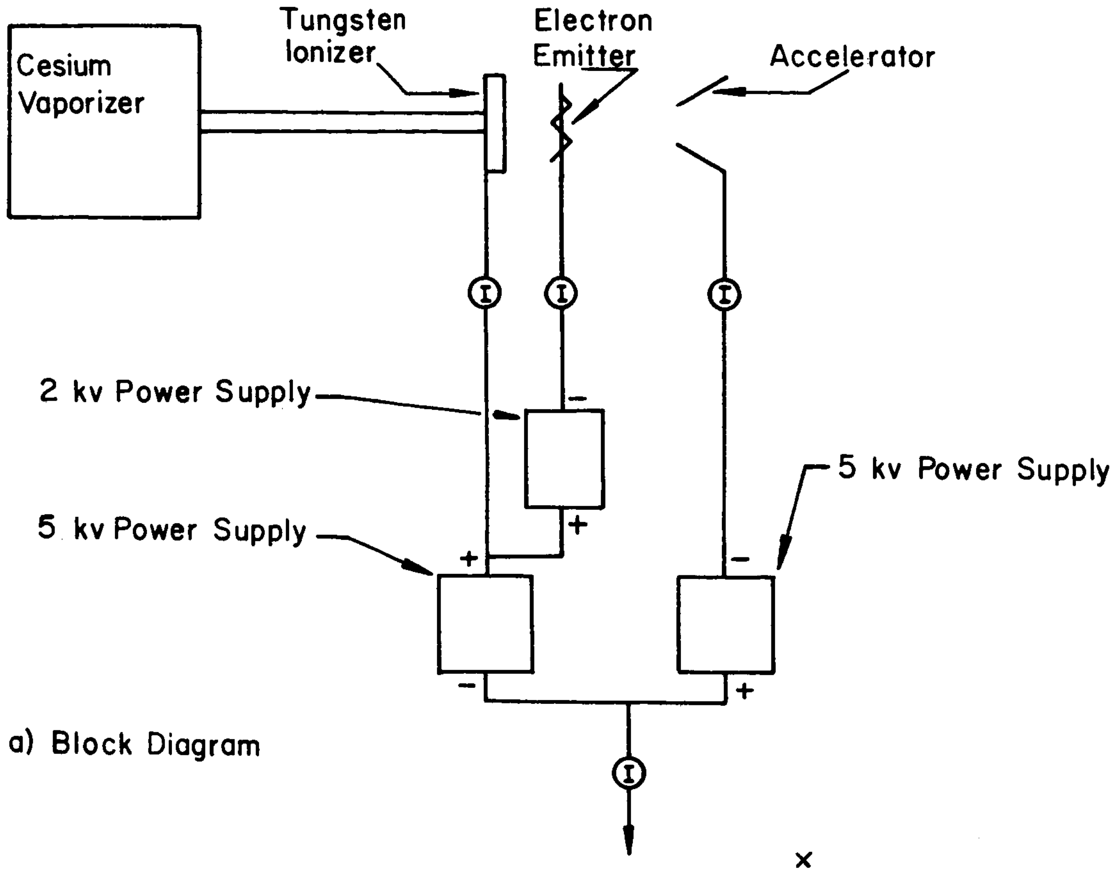
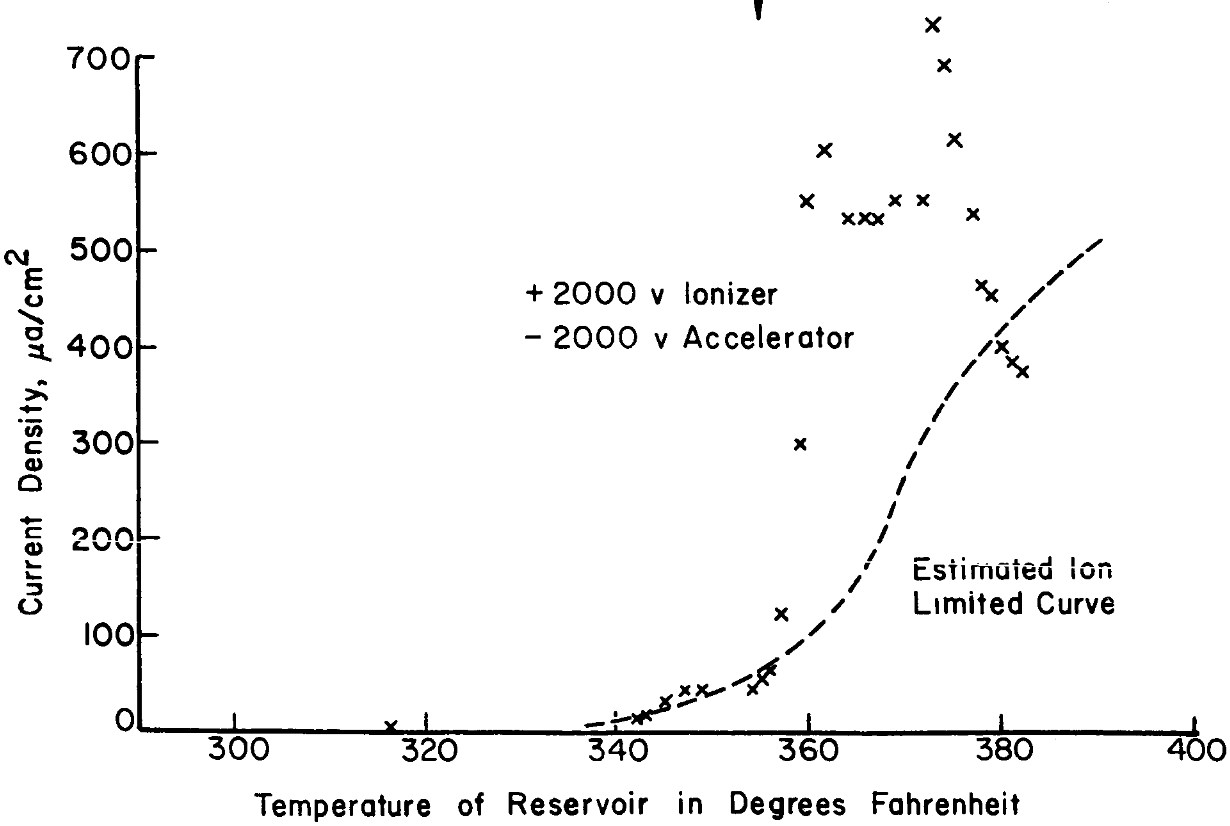


Figure 6. - Electron Emission Wire Across the Ionizer Face.

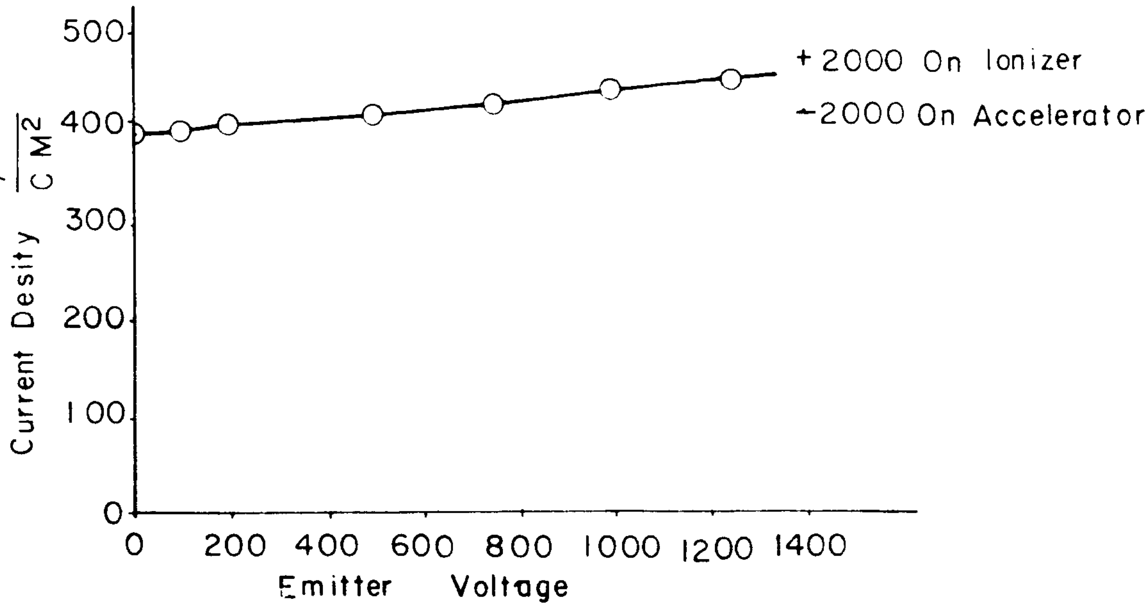


a) Block Diagram

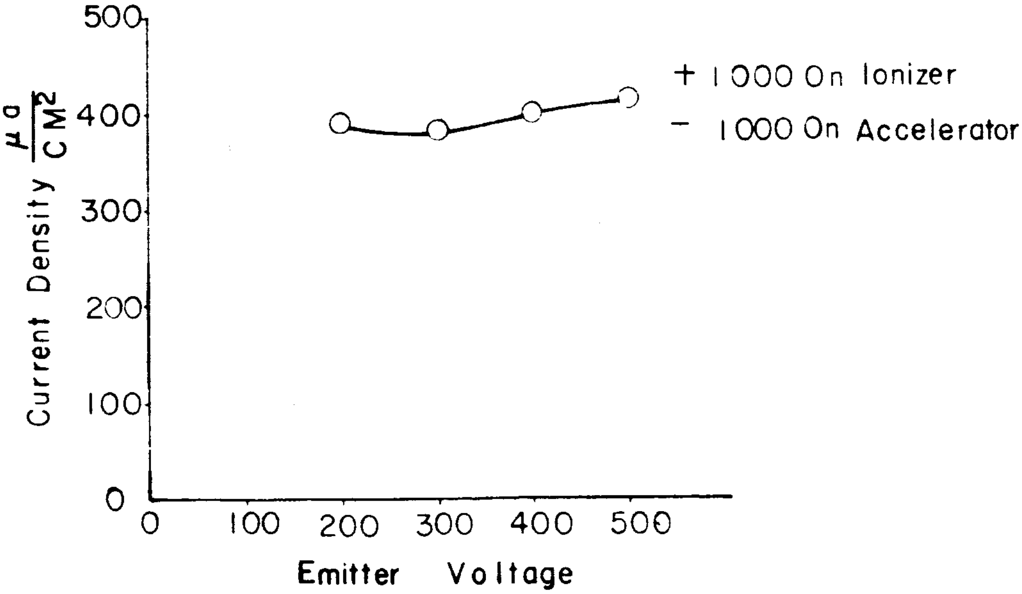


b) Current Density Versus Reservoir Temperature. (No Forced Electron Emission)

FIG. 7. - OPERATION OF ION ACCELERATOR SYSTEM WITH AN ELECTRON EMITTER.



(C) CURRENT DENSITY AS A FUNCTION OF ELECTRON EMITTER VOLTAGE (NO FORCED EMISSION)



(d) CURRENT DENSITY AS A FUNCTION OF EMITER VOLTAGE WITH ELECTRON EMISSION (8.5 TO 9.0 ma EMISSION)

FIGURE 7 (CONCLUDED)

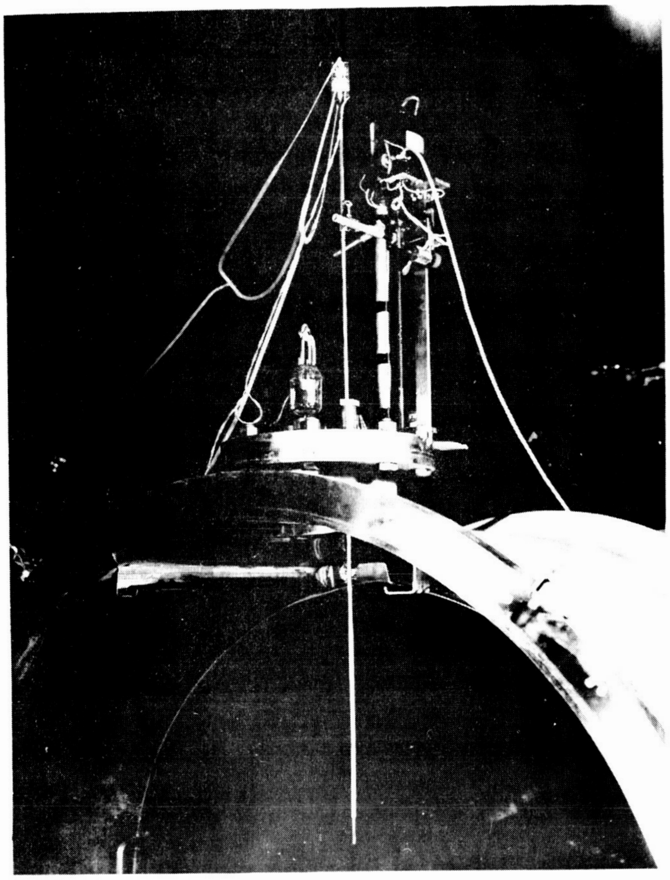


Figure 3. - Hot Wire Calorimeter Probe Mounted in the Vacuum Chamber.

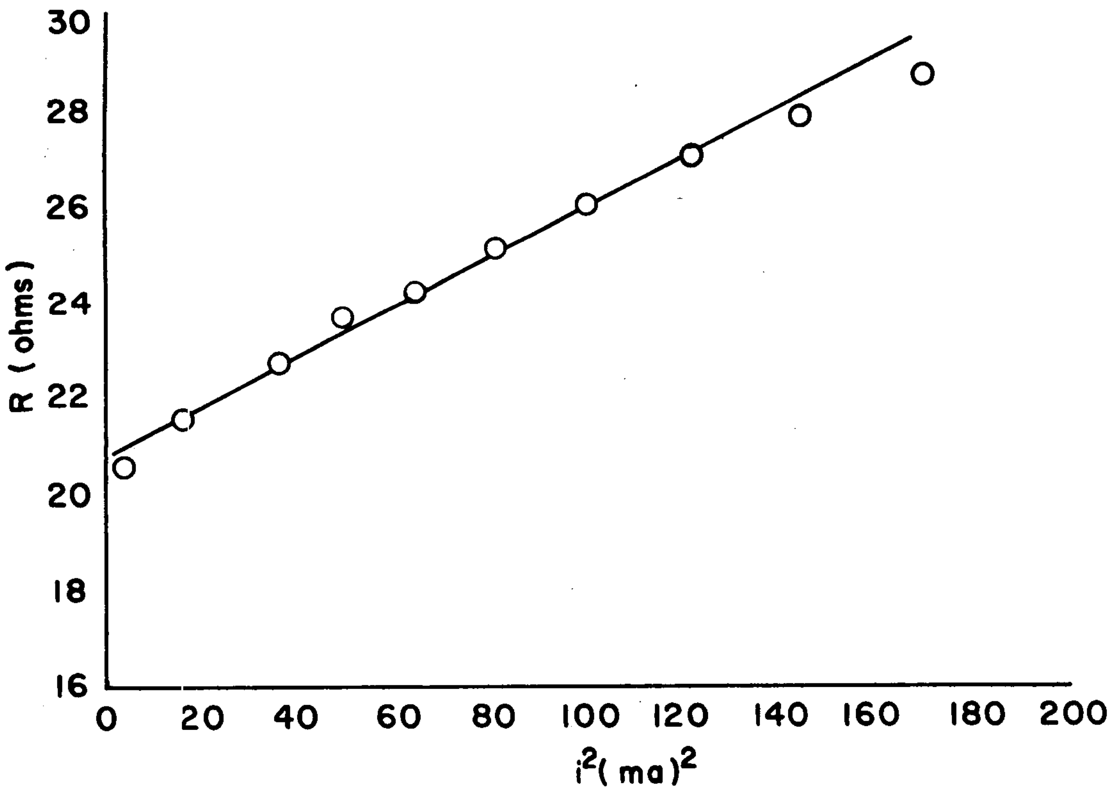


FIG. 9 CALIBRATION CURVE FOR A HOT WIRE CALORIMETER

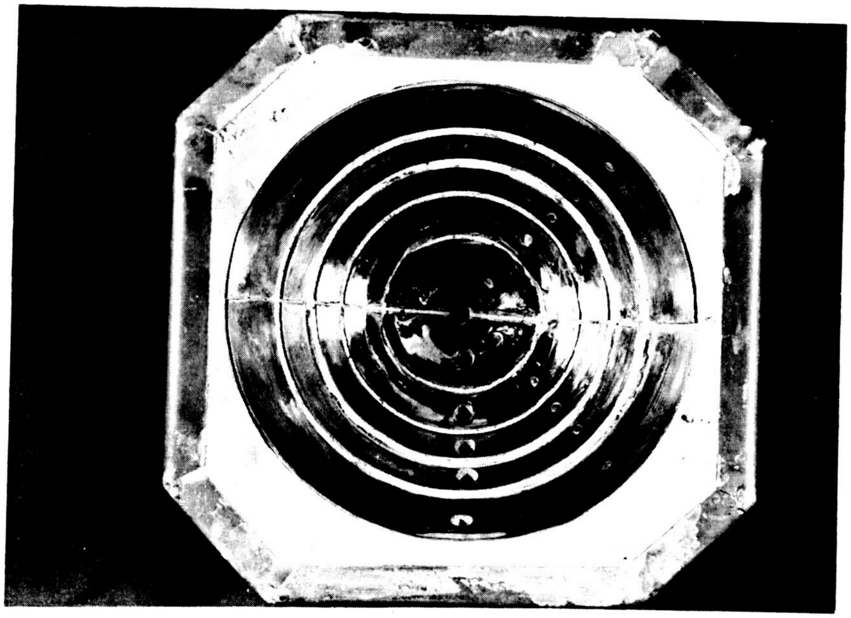


Figure 10. - ~~Ion Velocity Analyzer~~ Secondary Electron Collector.

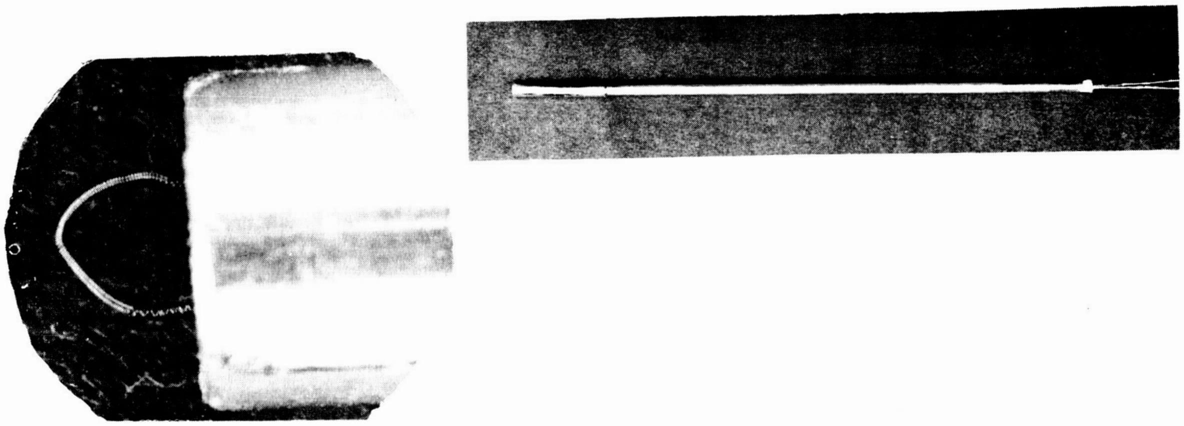
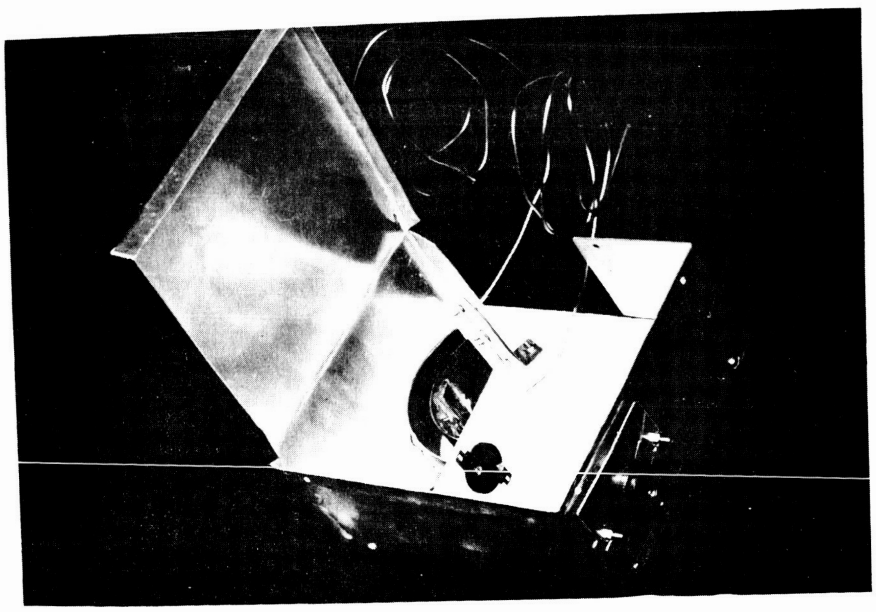


Figure 11. - Floating Emission Probe.



Ion Velocity Analyzer

Figure 12. - ~~Secondary Electron Collector~~.

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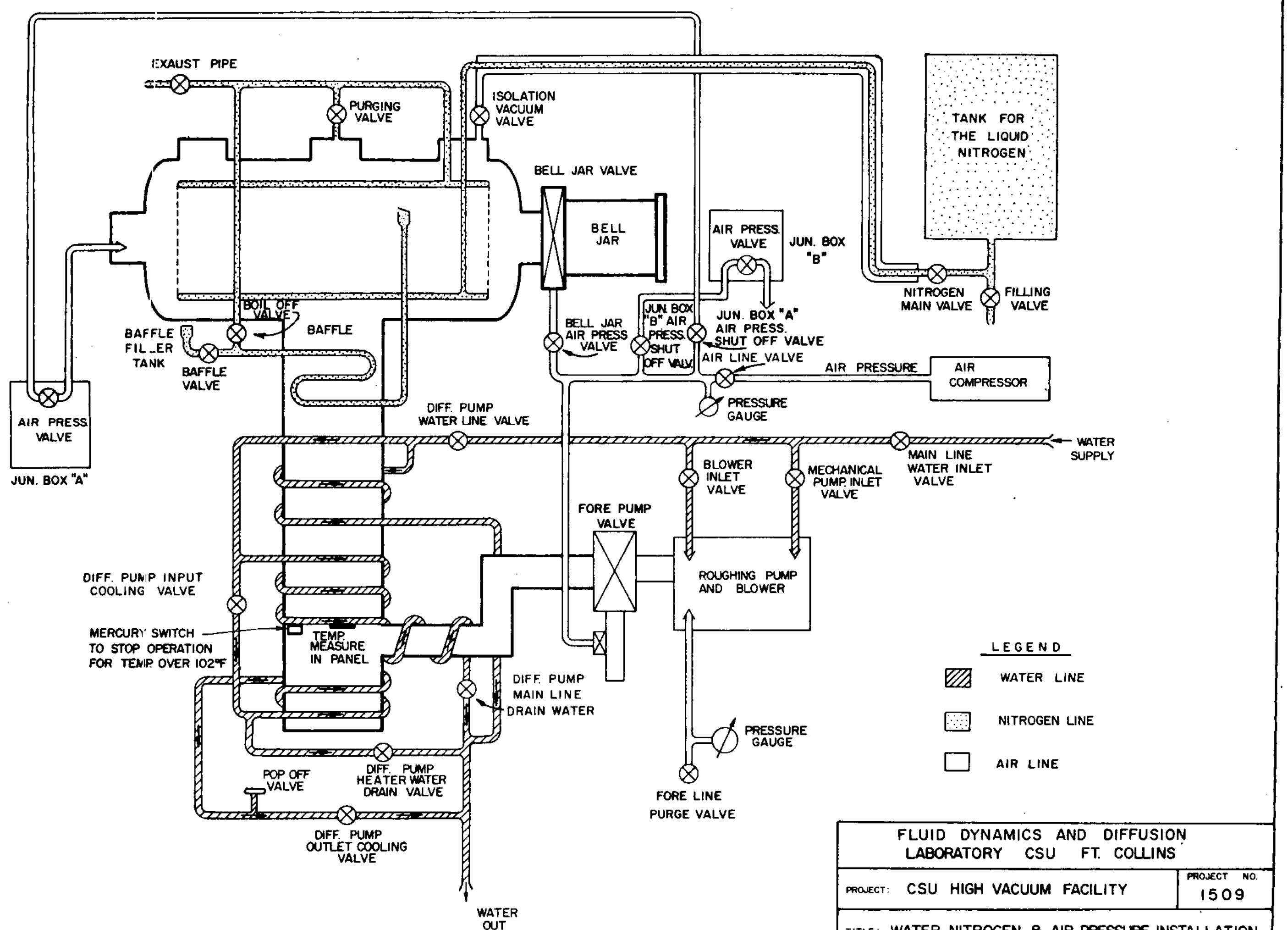
CSU HIGH VACUUM FACILITY

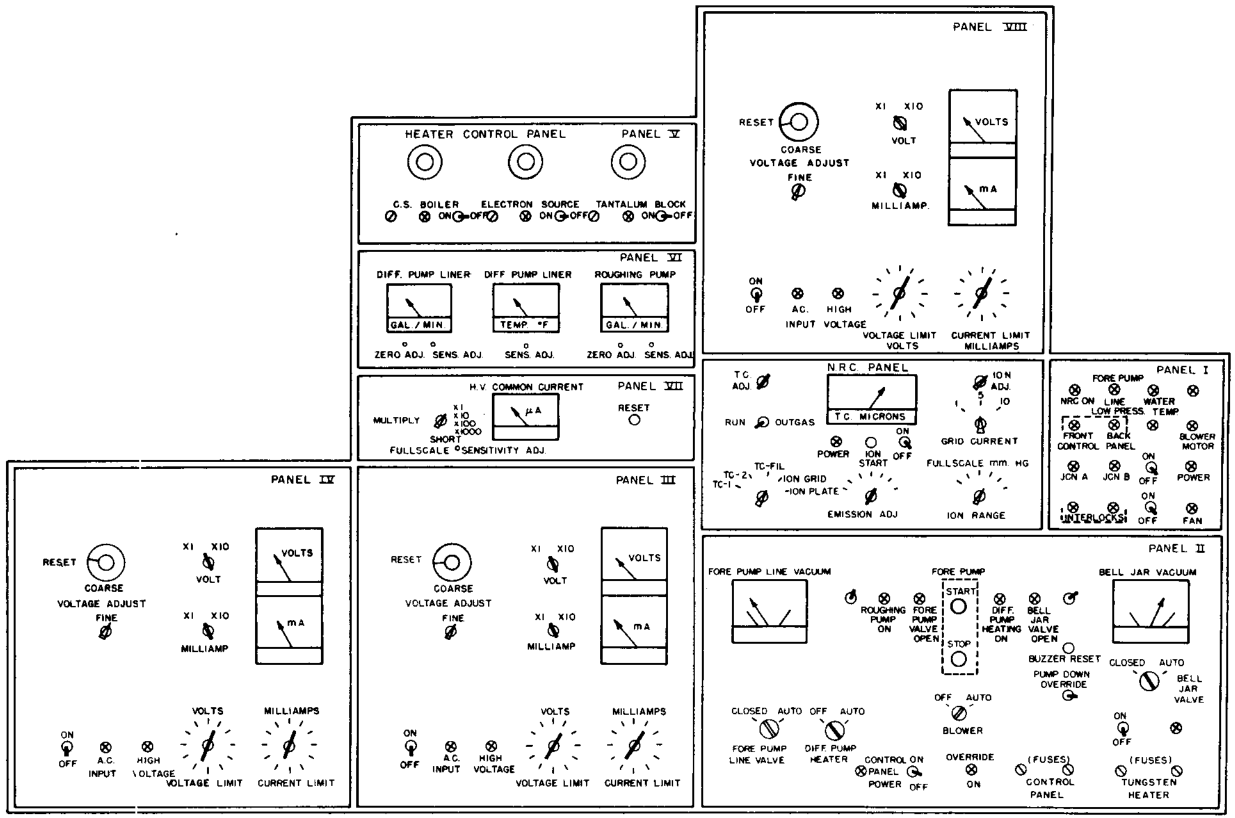
Manual of Operation and Schematics

August 1964



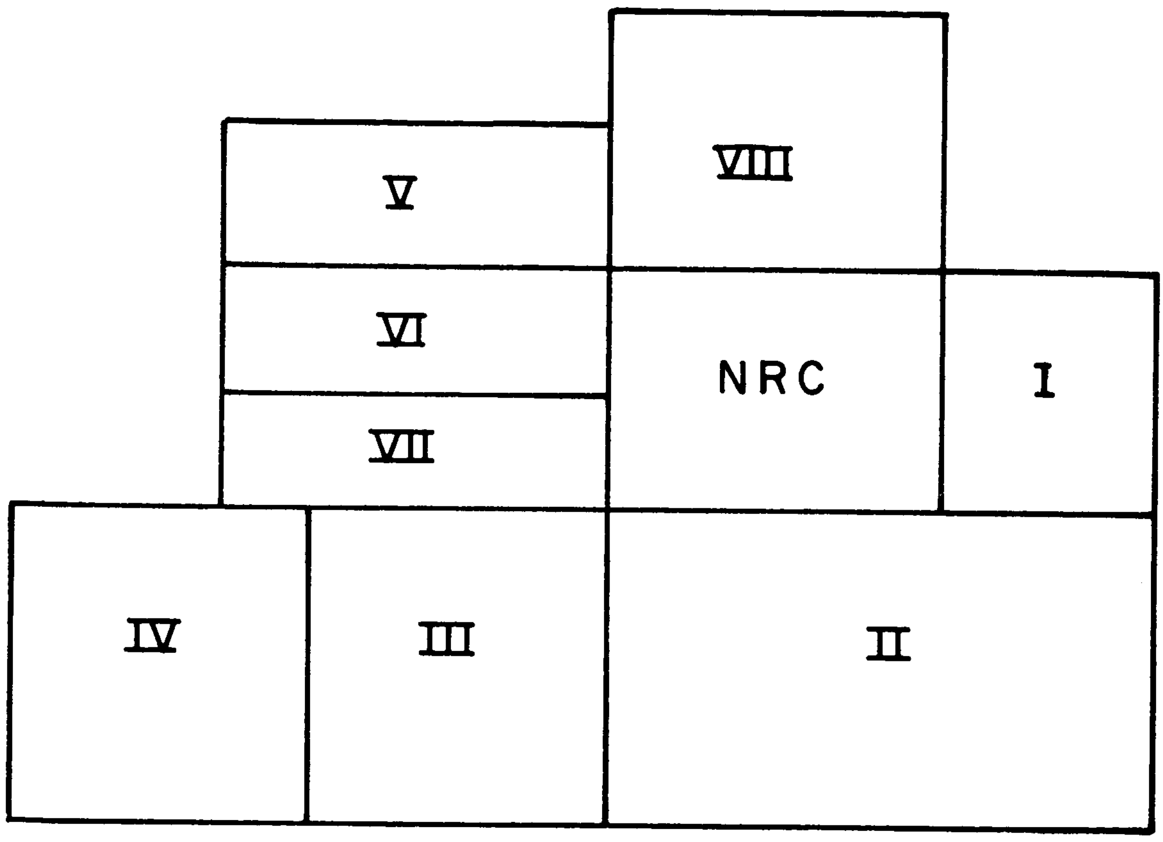
FLUID DYNAMICS AND DIFFUSION LABORATORY CSU FT. COLLINS

PROJECT: CSU HIGH VACUUM FACILITY	PROJECT NO. 1509
TITLE: WATER, NITROGEN & AIR PRESSURE INSTALLATION	
DESIGN BY: ________ DATE: JULY 1964	DRAWN BY H. AKARI DATE: AUGUST 1964	SCHEMATIC NO.



FLUID DYNAMICS AND DIFFUSION LABORATORY CSU FT. COLLINS		
PROJECT CSU HIGH VACUUM FACILITY		PROJECT NO. 1509
TITLE: PANELS DISTRIBUTION OF THE CONSOLE		
DESIGN BY L. W. MAXWEL DATE JULY 1964	DRAWN BY: HANAE AKARI DATE AUGUST 1964	SCHEMATIC NO.

PANEL NUMBERS



BEFORE OPERATION

Before operation of the facility all the switches and indicators have to be set according to the following description:

PANEL I

All indicators, off

Interlock lights and switches, off

PANEL II

"FORE PUMP LINE VALVE" in "AUTO"

"DIFF PUMP HEATER" in "OFF"

"BELL JAR VALVE" in "CLOSED"

"BLOWER" in "AUTO"

"CONTROL PANEL POWER" in "OFF"

All indicators are off.

"FORE PUMP LINE VACUUM" meter: High Pressure

"BELL JAR VACUUM" meter indicating: High Pressure

NRC PANEL

Power switch in "OFF"

"POWER" indicator off

"METER SELECTOR" in "TC-2"

For adjustment and calibration of the NCR panel see NCR-Manual.

PANELS III, IV, AND VIII

"AC" switch in "OFF"

"AC INPUT" indicator off

For operation of these panels, see "High voltage supplies".

VACUUM, AIR and NITROGEN VALVES

Before starting the pump-down it is necessary to check if the valves for vacuum and cooling supplies are in the proper position. The following table may help for the check out of all valves:

VALVE	LOCATION
ISOLATION VACUUM VALVE , open	1. Tower on the tank
PURGING VALVE, closed	2. Tower on the tank
EXHAUST PIPE, closed	2. Tower on the tank
BAFFLE VALVE, open	West side of the tank
BELL JAR AIR PRESS VALVE, closed	Bottom of Bell Jar
AIR LINE VALVE, open	Left side of the console
MAIN VALVE (NITROGEN), closed	Outside of the building
FILLING VALVE, closed	Outside of the building
MAIN LINE WATER VALVE, open	Left side of the console

OPERATION (Pumping-down)

1) The first thing to do before the operation of the vacuum facility is to set the water valves properly for the cooling of the pumps. The sequence of setting the valves is as follows:

VALVE	LOCATION
Close the "DIFF PUMP INPUT VALVE"	Downstairs
Close the "DIFF PUMP OUTLET COOLING VALVE"	"
WARNING: If the next two valves are not open the water line may blow out!	
Open the "Drain Cock" of the "DIFF. PUMP OUTLET COOLING VALVE"	Downstairs
Open the "POP OFF VALVE"	"

OPERATION (Pumping-down)	LOCATION cont'd"
Open the "DIFF PUMP HEATER WATER DRAIN VALVE" to drain water, when this line is empty close the valve.	Downstairs
Open the "BLOWER INLET VALVE"	Downstairs
Open the "MECHANICAL PUMP INLET VALVE" only 1-1/2 turns	Downstairs
Permanent open have to be the "DIFF PUMP WATER LINE VALVE" and the "DIFF PUMP MAIN LINE DRAIN VALVE".	Downstairs

2) CONNECTION OF THE AC LINES

Switch on the "110 MAIN DISCONNECT" switch, to supply power to the console and all AC outlets.	Downstairs on the south wall of the building .
Switch on the "440 MAIN DISCONNECT" switch, to supply power to the diffusion pump heaters, roughing pump and blower.	Downstairs on the south wall of the building.
Switch on the "110 CONSOLE SWITCH" (red) to supply power to the panels I, III, IV, and VIII.	On the left side of the console.
Switch on the "440 CONSOLE SWITCH" to supply power to the pumps and blower.	On the left side of the console.

OVERLOAD OF AC LINES

If some of the AC lines are accidentally overloaded, the "CIRCUIT BREAKER LOAD CENTER" open that circuit. The breakers are:	On the left side of the console.

1 "Control panel plug mold front" under the console

4-5 "30 Amps for panels II and V"

OPERATION (Pumping-down) cont'd: LOCATION cont'd:

13 "Control panel plug mold back (Back of the console)

14 "Plug mold south end", for all the south plug molds of the facility.

15 "Plug mold north end" for all the north plug molds of the facility.

Indicators on:

3) Switch on "CONTROL PANEL POWER". It switches on the power supplies of the instruments in the panels — "CONTROL PANEL ON"

4) Switch in NRC-panel, the "METER SELECTOR" to "TC-2" position, "FULL SCALE mmHG" to "10^{-3}"

5) Switch "ON" the NRC power switch — NRC "POWER", "NRC ON"

6) Open "AIR LINE VALVE" for air pressure The "AIR PRESSURE GAUGE" has to indicate between 70 and 80 psi.

7) Open "MAIN LINE WATER VALVE" and adjust valves to obtain at least: in Panel 6 for "DIFF PUMP LINER": 5 Gal/min and for the "ROUGHING PUMP": 2 Gal/min.

8) The temperature of the "DIFF PUMP LINER" has to be less than 100° F. Panel 6.

9) Depress "PUMP DOWN OVERRIDE" until valve is open and then depress "FOREPUMP START". Be sure that the mechanical pump (Roughing pump) turns counter clock wise looking at the pump west to east. This pump is downstairs. — "OVERRIDE ON" "ROUGHING PUMP ON" "FOREPUMP VALVE OPEN"

10) Set the upper and lower limits of the "FORE PUMP LINE VACUUM" meter.

OVERLOAD OF AC LINES cont'd: | Indicators on: cont'd:

11) After a few minutes the blower will be automatically started. This usually takes 10 minutes when starting from atmospheric pressure in tank. — "BLOWER MOTOR"

12) After a certain vacuum is reached, the "OVERRIDE ON" indicator will be off. The level where the "OVERRIDE ON" indicator turns off, depends on the upper limit set in the "FORE PUMP LINE VACUUM" meter.

13) When the "FORE PUMP LINE VACUUM" meter indicates the upper limit, the diffusion pump can be started but first it is necessary to follow the next steps in order to operate the nitrogen's cooling system. — "WATER TEMP."

14) Open the "BAFFLE VALVE" and fill the baffle of the Diffusion Pump with liquid nitrogen. This can be obtained from the liquid nitrogen main tank outside of the building by opening the "FILLING VALVE".

15) The facility has to be operated for a longer time with the roughing pump and blower. The baffle has to be refilled continuously until the exhaust line of the baffle is completely frosted and the pressure in the facility goes down to about 3×10^{-4} mmHg.

16) Turn on the "DIFF PUMP HEATER" switch to "AUTO". — "DIFF PUMP HEATER ON"

17) When the pressure is about 1.2×10^{-6} open the nitrogen line.
18) Close the "BAFFLE VALVE"
19) To operate the nitrogen line, open the "MAIN VALVE", outside of the building very slowly to approximately 1/2 turn. If too much nitrogen goes out in the "EXHAUST PIPE" turn the "MAIN VALVE" back to about 1/4 turn. This operation of opening more or less the "MAIN VALVE" has to be made many times during the operation of the facility to get the proper flow of nitrogen.

CLOSEDOWN OPERATION

Before increasing the pression in the tank, it is very important to disconnect all the devices in the experiment that can be damaged by the higher pressures. It is also very important to be careful with the operation of the NRC-panel when the pressure in the facility increases.

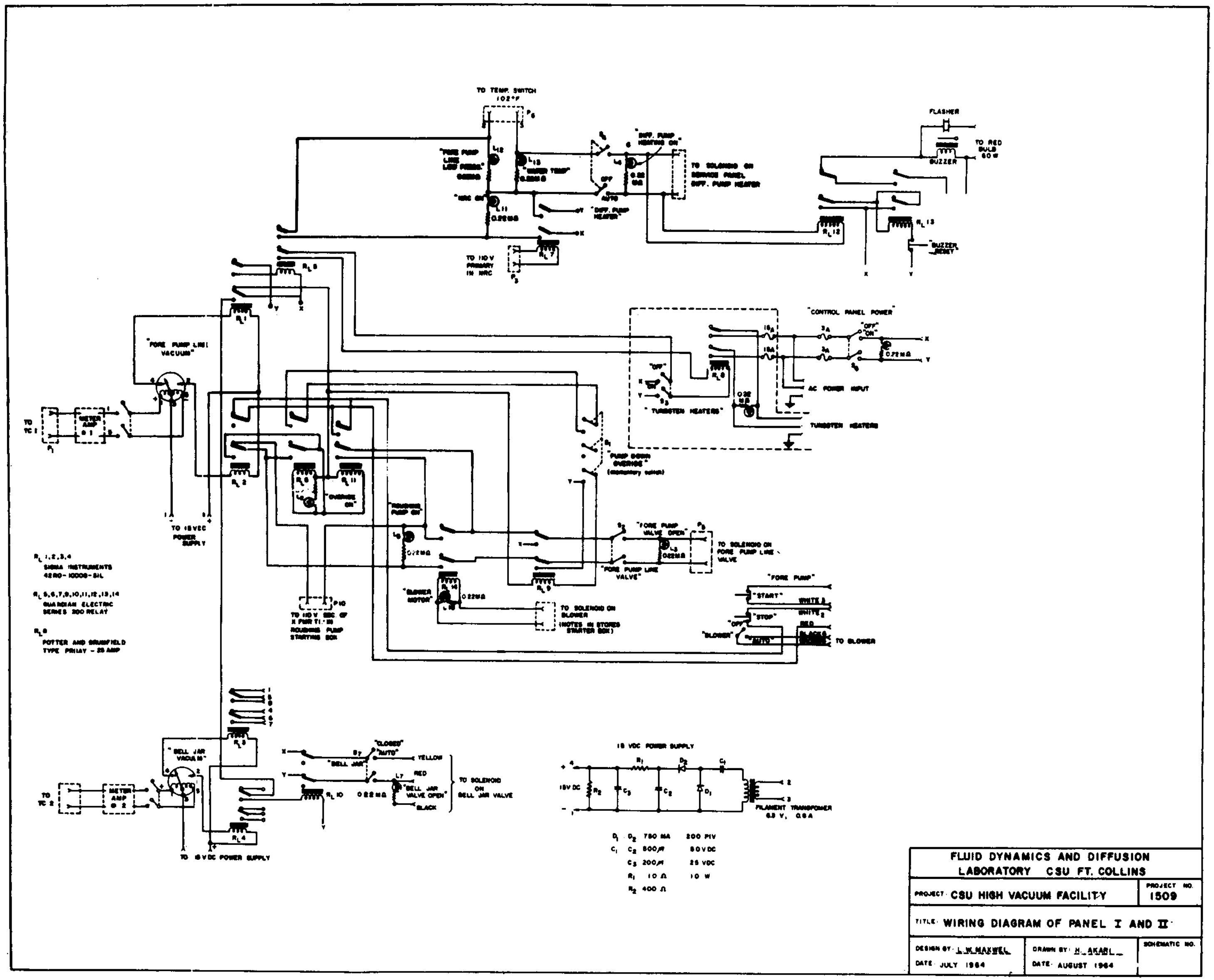
	LOCATION
1) Turn the "DIFF PUMP HEATER" switch to "OFF"	Panel II
2) Open the "DIFF PUMP INPUT COOLING VALVE" very slowly avoiding too much cold water flowing in the lowest cooling circuit. At the same time steam will flow out from the "POP OFF VALVE" and the "Drain cock" of the "DIFF PUMP OUTLET COOLING VALVE". When too much cold water flows in the lowest cooling circuit, the high temperature of the lines will create steam (bubbles) and the operator can realize their presence by the noise it produces.	

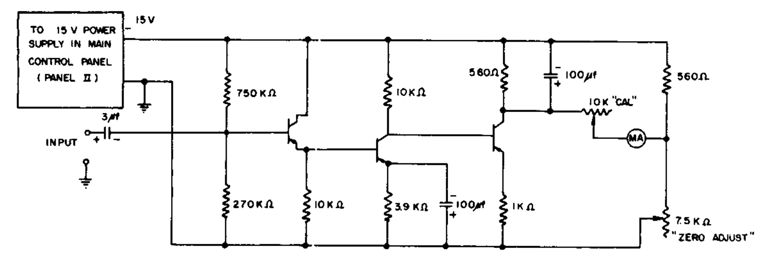
CLOSEDOWN OPERATION cont'd:	LOCATION cont'd:
After 15 or 20 minutes water will flow out from the "POP OFF VALVE" and the "Drain cock of the "DIFF PUMP OUTLET COOLING VALVE", then	
3) Close the "POP OFF VALVE" and the "Drain cock" of the "DIFF PUMP OUTLET COOLING VALVE", and at the same time open slowly the "DIFF PUMP OUTLET COOLING VALVE". It takes approximately 2 hours until the temperature of the diffusion pump's heaters drops to about 200^{0}F.	
4) Close the "NITROGEN MAIN VALVE".	Outside of the building
5) Depress "STOP" in panel II, to turn off the mechancial pump and blower.	Panel II
6) Close the "MAIN LINE WATER VALVE"	Left side of the console
7) Close the "AIR LINE VALVE"	Left side of the console

After following the above instructions it is possible to switch off the power in all the panels and equipments. It is strongly recommended to switch off the "110 CONSOLE SWITCH" (red) before touching or coming close to the high voltage connections of the facility. This switch disconnects the high voltage power supplies.

PURGING

To let air into the tank open the "EXHAUST PIPE"	2. Tower on the tank
Open the "PURGING VALVE" about 4 or 5 turns and after 15 minutes open it completely.	2. Tower on the tank
Open the "FORELINE PURGE VALVE"	Left side of the console.

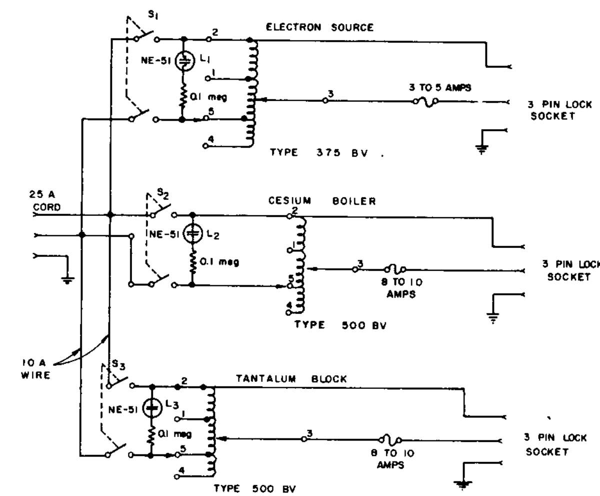

FLUID DYNAMICS AND DIFFUSION
LABORATORY CSU FT. COLLINS
PROJECT: CSU HIGH VACUUM FACILITY
PROJECT NO. 1509
TITLE: WIRING DIAGRAM OF PANEL I AND II
DESIGN BY: L.W. MAXWELL
DATE: JULY 1964
DRAWN BY: H. AKARI
DATE: AUGUST 1964
SCHEMATIC NO.
TO TEMP. SWITCH 102°F
FLASHER
TO RED BULB 60 W
BUZZER
"CONTROL PANEL POWER"
AC POWER INPUT
TUNGSTEN HEATERS
"TUNGSTEN HEATERS"
"FORE PUMP LINE VACUUM"
TO 15VDC POWER SUPPLY
TO SOLENOID ON FORE PUMP LINE VALVE
"FORE PUMP"
"START"
"STOP"
"BLOWER"
"AUTO"
TO BLOWER
TO SOLENOID ON BLOWER
"BELL JAR VACUUM"
TO 15VDC POWER SUPPLY
YELLOW
RED
BLACK
TO SOLENOID ON BELL JAR VALVE
15 VDC POWER SUPPLY
15V DC
FILAMENT TRANSFORMER 6.3 V, 0.6 A
D1 D2 750 MA 200 PIV
C1 C2 500μf 50 VDC
C3 200μf 25 VDC
R1 10 Ω 10 W
R2 400 Ω
RL 1,2,3,4 SIGMA INSTRUMENTS 42RO-10000-SIL
RL 5,6,7,9,10,11,12,13,14 GUARDIAN ELECTRIC SERIES 200 RELAY
RL 8 POTTER AND BRUMFIELD TYPE PR11AY - 25 AMP



FLOW METER AMPLIFIER

DESIGNED: JIM CLINE

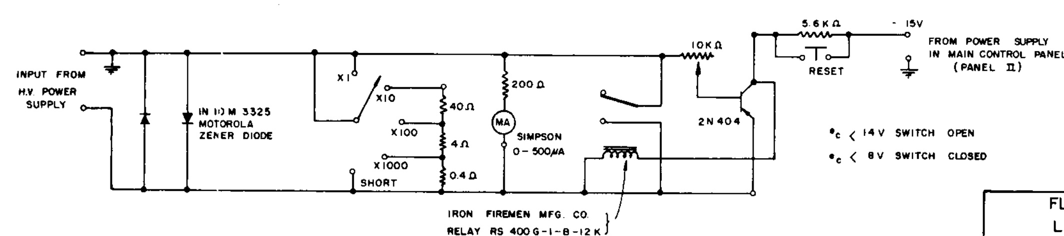
LOCATION PANEL VI



ION ENGINE SUPPLIES

DESIGNED: L.M. MAXWELL

LOCATION: PANEL V



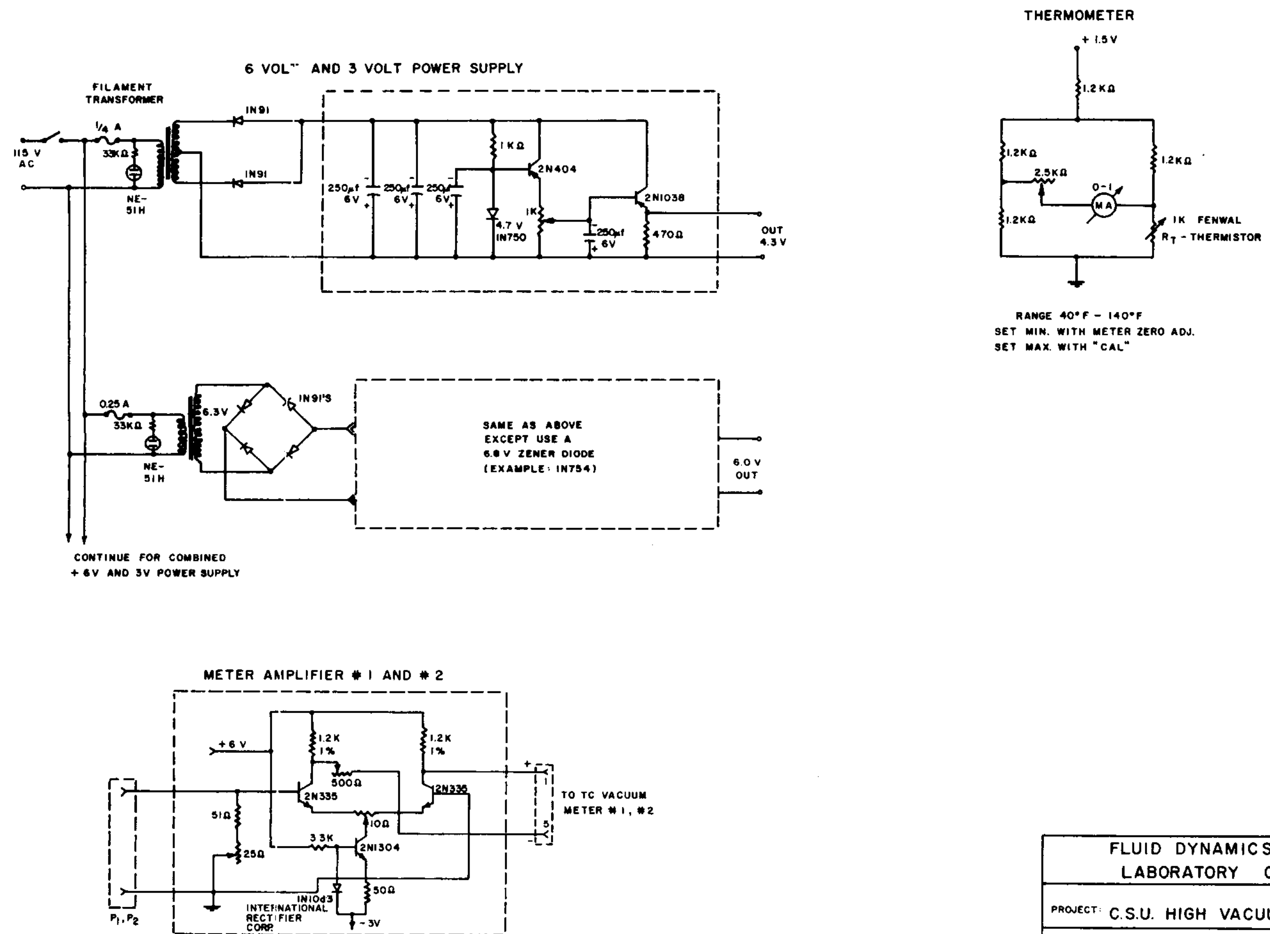
H.V. COMMON CURRENT METER

DESIGNED: JIM CLINE

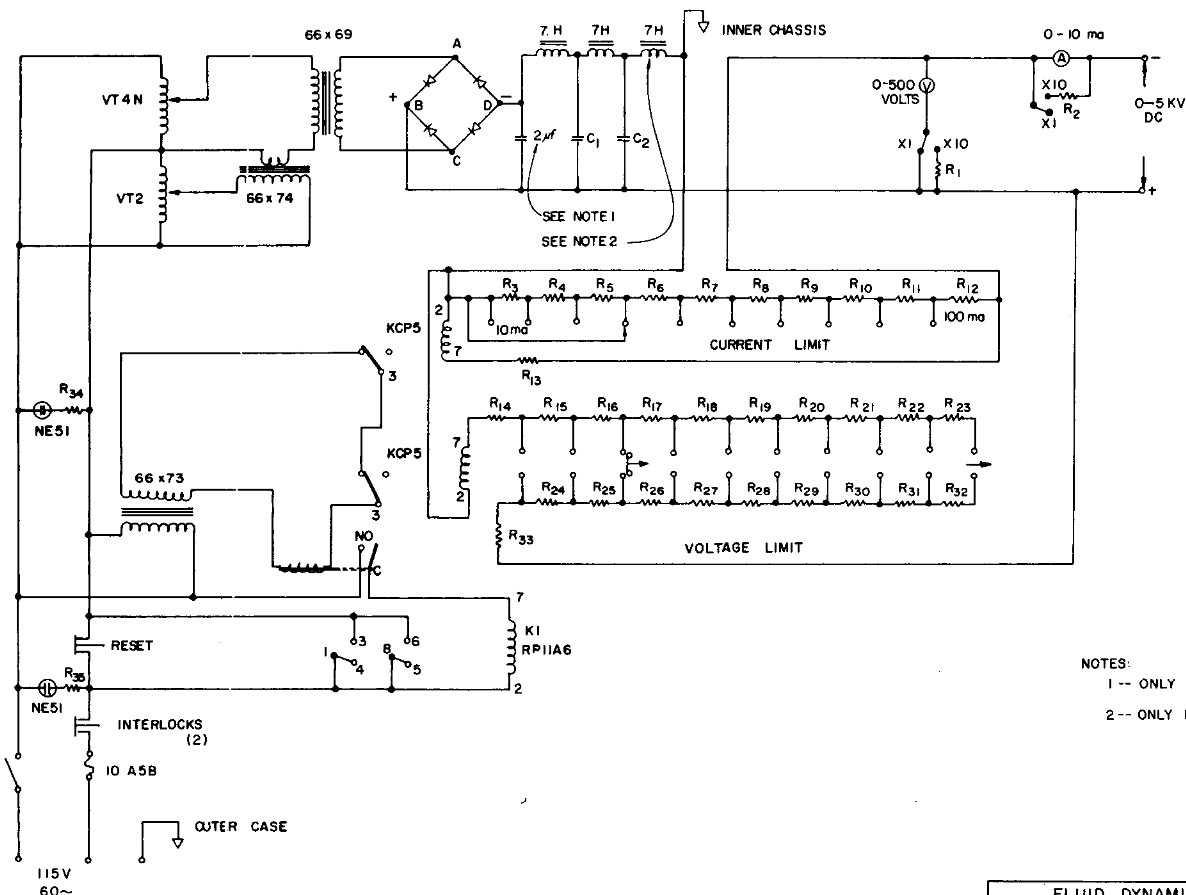
LOCATION: PANEL VII

FLUID DYNAMICS AND DIFFUSION LABORATORY C.S.U FT. COLLINS

PROJECT: CSU VACUUM FACILITY	PROJECT NO. 1509
TITLE: CONSOLE INSTRUMENT PANELS V, VI & VII	
DESIGN BY STAFF — DATE JULY, 1964 / DRAWN BY H. AKARI — DATE AUGUST, 1964	SCHEMATIC NO.



FLUID DYNAMICS AND DIFFUSION LABORATORY C.S.U. FT. COLLINS	
PROJECT: C.S.U. HIGH VACUUM FACILITY	PROJECT NO. 1509
TITLE: METER AMPLIFIER AND POWER SUPPLY	
DESIGN BY: C. FINN; DATE: 8/12/64	DRAWN BY: H. AKARI; DATE: 8/31/64
SCHEMATIC NO.	

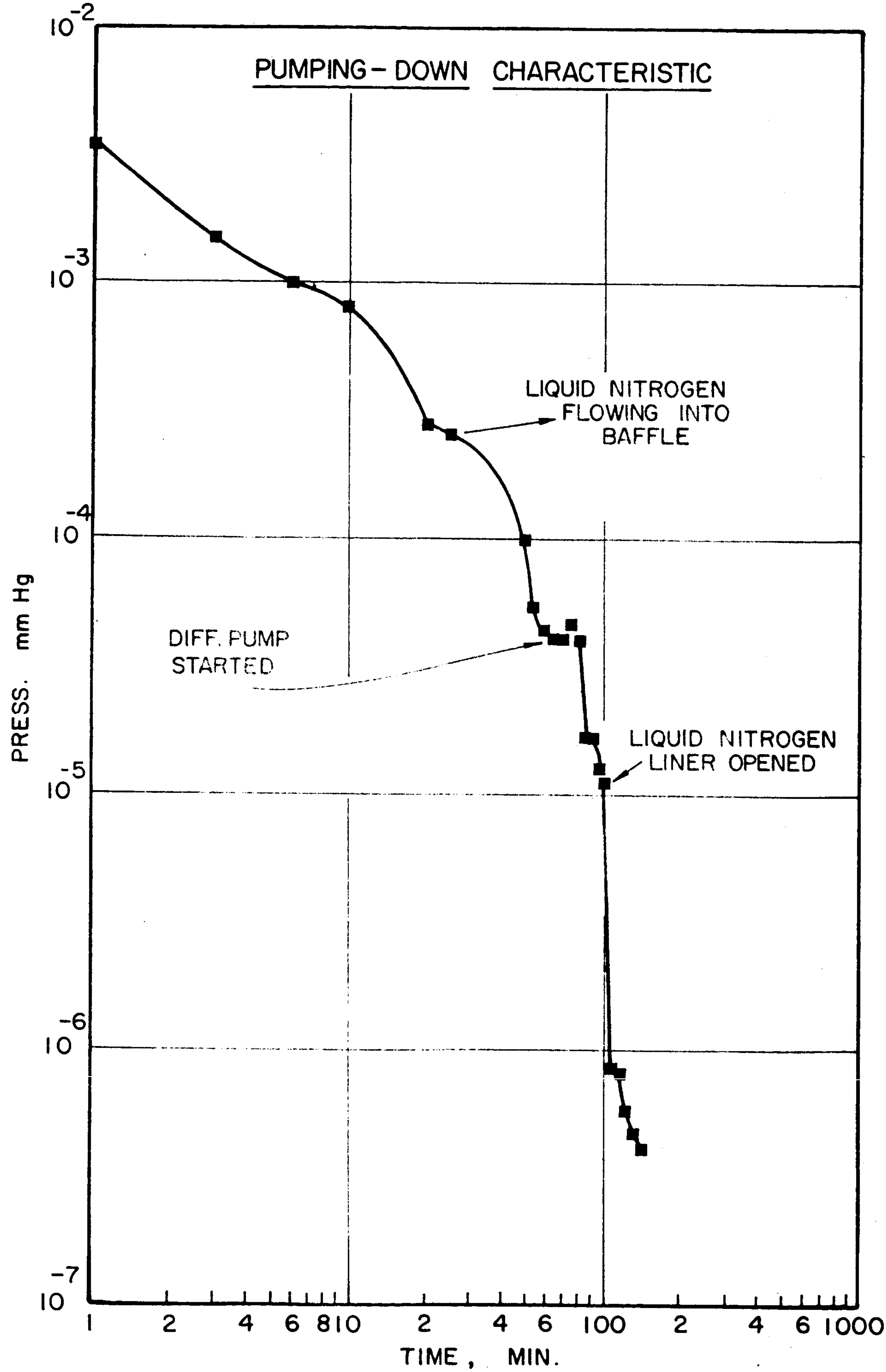


NOTES:
1 -- ONLY FOR THE 2KV P.S.
2 -- ONLY FOR THE 5KV P.S.

FLUID DYNAMICS AND DIFFUSION LABORATORY CSU FT. COLLINS	
PROJECT CSU HIGH VACUUM FACILITY	PROJECT NO 1509
TITLE HIGH VOLTAGE POWER SUPPLIES	
DESIGN BY SCINTILLONICS, INC DATE JUNE 1964	DRAWN BY H. AKARI DATE SEPT. 1964
SCHEMATIC NO.	

HIGH VOLTAGE POWER SUPPLIES COMPONENTS

Component	2 KV P.S.	5 KV P.S.
C_1	2 μ F	1.25 μ F
C_2	2 μ F	1.25 μ F
R1	1.8 M Ω	9 MΩ
R2	0.444 Ω	1.11 Ω
R3	1 KΩ	3.3 KΩ
R4	270 Ω	680 Ω
R5	120 Ω	270 Ω
R6	68 Ω	150 Ω
R7	47 Ω	100 Ω
R8	33 Ω	68 Ω
R9	27 Ω	47 Ω
R10	18 Ω	39 Ω
R11	15 Ω	27 Ω
R12	128 Ω	265 Ω
R13	1 KΩ	200-1000 Ω
R14	0	17 KΩ
R15	42 KΩ	100 KΩ
R16	0	22 KΩ
R17	42 KΩ	100 KΩ
R18	0	22 KΩ
R19	42 KΩ	100 KΩ
R20	0	22 KΩ
R21	42 KΩ	100 KΩ
R22	0	22 KΩ
R23	42 KΩ	100 KΩ
R24	0	22 KΩ
R25	42 KΩ	100 KΩ
R26	0	22 KΩ
R27	42 KΩ	100 KΩ
R28	0	22 KΩ
R29	42 KΩ	100 KΩ
R30	0	22 KΩ
R31	42 KΩ	100 KΩ
R32	0	22 KΩ
R33	42 KΩ	100 KΩ


PUMPING - DOWN CHARACTERISTIC
LIQUID NITROGEN FLOWING INTO BAFFLE
DIFF. PUMP STARTED
LIQUID NITROGEN LINER OPENED
PRESS. mm Hg
TIME, MIN.
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
1
2
4
6
8
10
2
4
6
100
2
4
6
1000